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fluor-spar and potassium bisulphate, as a blow-pipe reagent in the detection of boron and the alkalis in their mineral combinations. (*C. N.*, 49—269.)

According to E. Fischer, para-amido-dimethyl-aniline sulphate is a much more delicate test for hydrogen sulphide than either lead acetate or sodium nitro-prusside. (*J. C. S.*, CCIV—109.)

For the detection of free sulphuric acid in vinegar, Wharton evaporates down to a syrup, lets cool to a hand-heat, and then stirs in a few centigrams of potassium chlorate. If there is more than one per cent. of sulphuric acid the mass ignites violently. Smaller quantities are detected by the odor of chlorine. (*C. N.*, 50—68.)

R. T. Thompson has made a large number of observations on the use of litmus, rosolic acid, methyl-orange, phenacetolin, and phenolphthaleïn as indicators. The writer can only refer to the original articles. (*C. N.*, 49—32, 38 and 119.)

EXPERIMENTS UPON SUPER-HEATED LIQUIDS AND UPON THE SUPER-SATURATION OF VAPORS.

EDWARD L. NICHOLS, PH. D.

I.

It is the purpose of this paper to describe some experiments upon the behavior of liquids heated beyond their boiling points under conditions which prevent ebullition, and of vapors cooled below the temperatures at which they ordinarily return to the liquid state.

Professor James Thomson*, in a discussion of Andrews's† well-known experiments on the continuity of the liquid and gaseous states, has shown that there are reasons for thinking that under proper conditions liquids might be converted into vapor even below the critical temperature without discontinuity; and he has shown the general form which the curve indicating the changes of volume might be expected to take. The change of state may be brought about by decrease of pressure or by increase of temperature. The former was the method adopted by Andrews in his research upon carbonic acid, and the curves given in Thomson's paper, based upon those experiments, are isothermal curves indicating variations of volume with the pressure. All that he has said on this subject is applicable, however, to methods in which the temperature is varied.

When heat is applied to a liquid at ordinary pressures, volume and temperature vary simultaneously until the boiling point is reached, when the temperature becomes constant and the familiar expansion-curve becomes a straight line, parallel to the axis along which volumes are measured. Figure 1 shows this curve (A B F G) in the case of water heated at a pressure of 760 mm. We know from the experiments of Donny‡, Dufour§ and others upon superheated liquids, that the curve does not always take this form, since water, holding no absorbed gases and contained in perfectly clean vessels, can be heated far above its boiling point without ebullition. The general form pointed out by Thomson for the isothermal method, but applied to the isobaric expansion-curve, is shown in the dotted line (B C D E F). The condition under which a liquid will follow the limb B C D is the absence of absorbed gases. The limb F E D should be obtained by cooling a vapor in the absence of its liquid.

*James Thomson; Report of the British Association for the Advancement of Science, 1871; also Proceedings of the Royal Society, 1859 and 1871.

† Andrews; Philosophical Transactions, 1869.

‡ Donny; Annales de Chimie, 1846, 3d series, Vol. XVI.

§ Dufour; Bibliotheque Universelle, Archives 1861, Vol. XII.

The experiments to be described here consisted of attempts to fulfil these conditions, and thus to compel the substance in changing state to follow the continuous instead of the broken curve.

II.

By the simple method described to the Academy of Science at its last meeting,* I have found it easy to prevent water in newly-blown bulbs from boiling until 130° was reached, at which temperature, as in Donny's experiment, it invariably boiled explosively. Sulphuric ether and bisulphide of carbon in such bulbs frequently attained a temperature of 80° or 90° before boiling, and then burst explosively into gaseous form. Above the normal boiling point, the expansion of the liquid was very rapid, but I have not as yet succeeded in measuring it. The liquid in these experiments was separated from the outer air by a short column of mercury, and when the change of state occurred, this mercury was driven forcibly from the tube, together with the entire contents of the bulb.

Upon placing a bulb filled with ether in a paraffine bath at 200° , the bead of mercury being omitted, I found to my surprise that the ether, as in former trials, refused to boil, and that although exposed to a temperature vastly above its boiling point, it remained perfectly quiescent, going over into the gaseous state without ebullition. That the liquid was superheated, was shown by its rapid expansion, but this expansion was followed by a diminution of volume, which continued until the liquid had all disappeared. Inspection showed that the ether, during this process of contraction, *was in the spheroidal state*. From previous well-known experiments upon the spheroidal state, we know that the temperature of the liquid is always considerably below the boiling point. In this case the transfer from the liquid to the gaseous state occurred under conditions such that the expansion-curve was a continuous one. The general form was evidently that predicted by Thomson—in the paper already cited—the temperature and volume increasing to the point C (fig. 1), several degrees above the boiling point, when the liquid, without boiling, assumed spheroidal form, and the temperature fell to a minimum at E, considerably below the boiling point.

The experiment as above described was repeated many times, and always with the same result. It succeeded equally well where bisulphide of carbon was used instead of ether, and would probably succeed in case of water in a bath of temperature sufficient to throw that liquid into spheroidal form. Several attempts to repeat this experiment with a thermometer immersed in the liquid failed. Nuclei of occluded gases, upon the bulb of the thermometer, which no amount of cleansing with acids or caustic alkali entirely removed, invariably induced boiling of the liquid as soon as it was placed in the paraffine bath. Probably the only method by which the temperature of the liquid during the entire experiment could be determined, would be by the use of a newly blown and consequently perfectly clean thermometer. I hope, by means of an air thermometer of proper form, to succeed in measuring these temperatures and also the accompanying changes of volume.

The conditions under which liquids may be converted into vapor without presenting the usual broken expansion-curve may be briefly stated as follows:

1. The liquid must be free from absorbed gases, and it must be heated in a vessel upon the inner surface of which no gases are occluded.
2. It must be subjected to a temperature sufficient to produce the spheroidal state without ebullition.
3. It must have a free surface in contact with the air.

* A Class-room Experiment on Superheated Liquids: Proceedings of the Kansas Academy of Science, 1883. [This method consists of removing the air from water by repeated boiling in a small and newly-blown bulb with a narrow neck, after which it is separated from the atmosphere by a bead of mercury. Upon heating again, ebullition is invariably delayed until, at about 130° , the entire contents of the bulb is expelled by explosive boiling.]

III.

Upon the super-saturation of vapors there exist, so far as I know, no published researches; and aside from Professor Thomson's paper (already cited) and a brief allusion to that paper in Maxwell's* *Theory of Heat*, the subject has attracted but little attention. My attempts to realize the conditions under which vapors might be cooled below the boiling point without condensation were begun in 1880. Believing the immediate cause of condensation to be the presence of nuclei of the substance in question in liquid form, † I collected steam in inverted glass tubes filled with heated oil; the mouths of the tubes dipped into an oil bath, and in some cases the whole tube was submerged. The steam, however, condensed upon the sides of these tubes, in the form of dew, whenever the bath was allowed to cool to the boiling point of water. The film of oil upon the glass was doubtless insufficient to prevent the steam from coming in contact with the hygroscopic surface of the glass.

Some experiments made in 1882 were more successful. A glass tube (fig. 2) 5 cm. in diameter and 50 cm. long, open at both ends and having two tubulatures through which thermometers were inserted, was placed with its lower end in a bath of mercury and filled with linseed oil. The mercury was heated to 150° and a few drops of water were introduced into the column of oil. Upon reaching the hot mercury at the bottom of the tube the water boiled, and bubbles of steam rose through the oil without condensing until a point was reached which had a temperature of 70°, when it condensed suddenly. During the course of the experiment, the oil being gradually heated from below, this 70° level rose and the point of condensation rose with it until the entire column of oil was hotter than 70°, when the steam condensed at the surface. Upon substituting bi-sulphide of carbon for the water in this experiment, and water for the oil, a similar result was reached. The bi-sulphide of carbon vapor rose uncondensed through water whenever the latter was above 35°, a temperature 10° below the boiling point of the substance. Steam generated outside the apparatus and introduced into the column of oil from below behaved in the same manner as that produced by boiling drops of water in the tube itself. When led, for comparison, into warm water, it condensed explosively, in the usual manner, until the water itself had begun to boil.

To determine whether other liquids than oil would serve as an envelope for the isolation and consequent super-saturation of steam, I introduced dry steam into moderately warm dry mercury. The behavior of the vapor within the mercury could of course not be directly observed, but the surface of the latter became coated with minute globules of water in the form of dew, indicating, I think, that it had risen through the mercury in the form of vapor and condensed at the surface. Whenever condensation below the surface occurred, as in the cases in which wet steam was used, no dew appeared and the water collected in considerable quantities before rising to the surface of the mercury.

I have recently repeated these experiments in a slightly modified form. A glass tube (fig. 3) rather more than a metre in length, two centimetres wide, and closed at the lower end, was filled with oil, and immersed to a depth of four or five centimetres in an oil bath at 200°. Such a column of oil heats slowly, and the temperature decreases

* Clerk Maxwell, *Theory of Heat*, p. 124.

† The view of the processes of ebullition and condensation upon which this opinion is based has been more clearly stated in Maxwell's treatise (just referred to) than in any work with which I am acquainted. According to this view they are special cases of the general process known as fluid diffusion. Ebullition consists of an inrush of liquid particles into gaseous nuclei contained within the body of the liquid or occluded upon the walls of the vessel. The absence of such nuclei precludes boiling and permits of super-heating. Condensation is the reverse process in which particles of a vapor enter liquid nuclei, becoming part of them and producing drops of the liquid. The absence of such nuclei might be expected from the nature of the case to prevent condensation and make super-saturation possible.

regularly and gradually from the bottom upward. Water introduced into the tube boiled upon reaching the bottom, and the vapor rose slowly until it reached a level possessing a temperature between 60° and 70° , when it condensed. The experiment was repeated many times, under varying conditions, and with different kinds of oil, but always with the same result.

IV.

In these experiments it was unfortunately impossible to measure the temperature of the vapor itself. It seems highly improbable that bubbles of steam rising slowly through a meter or more of oil would maintain a temperature thirty degrees above that of the surrounding liquid; and the following considerations, the result of repeated observation, are thought sufficient to show that the difference between the temperature of the vapor and the oil through which it passed was very small:

1. The bubbles of vapor contracted continually up to the moment of condensation, and as nearly as could be estimated the contraction was such as would have resulted had the bubbles assumed the temperature of the liquid through which they were passing.

2. The upward velocity of the bubbles varied greatly with the viscosity of the oil, being about 120 cm. per second in castor oil, and 200 cm. per second in linseed oil; but the apparent temperature of condensation, while it varied somewhat in different oils, being about 62° in castor oil, 67° in olive oil, and 70° in linseed oil, was lowest in the most viscous and highest in the most limpid of these oils. If there had been a great difference of temperature between the vapor and the oil, the *apparent* temperature of condensation would have been higher in the more viscous oils than in those through which the bubbles of steam rose more rapidly. That is to say, the temperature of the vapor at the time of condensation would be more nearly that of the surrounding oil in the case of viscous oils, because of the longer time for cooling.

3. The apparent temperature of condensation was not the same throughout the course of an experiment. It was somewhat lower at first when the vapor condensed near the bottom of the tube than when it passed to the top of the tube before liquefying. This would seem to indicate that the vapor did not instantly assume the temperature of the oil through which it was rising; but the apparent temperature of condensation did not vary more than four or five degrees between the bottom and top of a column (a metre long) of the most viscous of these oils.

4. Large and small bubbles had the same apparent temperature of condensation.

5. Steam confined within glass tubes, (below the surface of an oil bath,) as in the first experiment described in this paper, condensed as soon as the *bath* reached the boiling point of water. In this case the *apparent* temperature of condensation was also the *true* one, and I believe it may be so considered in all these experiments without serious error.

The temperature of condensation of super-saturated steam obtained by this method is as far below the boiling point as the temperature of explosive ebullition in Donny's experiments and those described in a previous paragraph lie above that point; *i. e.*, about 30° . The temperature 70° and 130° are then those of the maximum (C) and minimum (E) of the continuous expansion-curve. The portions B C and E F are plainly determinable. Under conditions which permit ebullition after super-heating, the portion C D E, as has been pointed out by Maxwell*, cannot be determined; but the experiment with ether in which the liquid did not boil at all, indicates conditions under which the curve is of a determinate character throughout.

As the boiling point approaches the critical temperature, the maximum and minimum become less marked, and finally disappear. Whether the curve at a given pressure varies also with the conditions of the experiment, as Dufour's experiment, in which

* Clerk Maxwell, Theory of Heat, p. 127.

water enveloped in oil boiled at 180° , and the different temperatures at which steam condensed in different oils (in my experiments) would seem to indicate, must be determined by further and more exhaustive research.

UNIVERSITY OF KANSAS, November 26, 1884.

STATISTICS ON COLOR-BLINDNESS IN THE UNIVERSITY OF KANSAS.

EDWARD L. NICHOLS, PH. D.

[Abstract.]

During the past two years I have tested the members of my classes in physics for color-blindness with the Holmgren worsteds. The primary object in these tests was the practical illustration of this interesting subject in the class-room, but the statistics thus collected have some features which may be of more general interest.

The most noteworthy of these is the unusual prevalence of "incomplete" green-blindness among our students. From the far more extended series of tests already made in Europe,* and elsewhere in this country,† it has been ascertained: that among men about 4 per cent. are completely color-blind; that "red" and "green" blindness are about equally prevalent; and that with very few exceptions women are not color-blind.

The results of my tests were in accordance with those made elsewhere, so far as the above-mentioned particulars are concerned. Of 137 young men subjected to the Holmgren test, five were found to be completely red-blind and four completely green-blind. Of 93 young women, one was completely red-blind. The percentage of those completely color-blind, (6.56 per cent for males,) while above the average, is not in excess of the percentages frequently obtained by other experimenters. (Dr. Feris, for instance, found in testing 501 French sailors that 8.18 per cent. of them were color-blind. Dr. Dor, who tested 611 women in Breslau, found 0.82 per cent. of them to be color-blind.) The number of cases in which the perception of green was notably deficient—in other words, the amount of incomplete green-blindness—was, however, surprisingly large. Besides the four persons classed as completely green-blind, no less than eighteen were found to be incompletely green-blind; so that, including the former, more than 16 per cent. of all the males tested were pronouncedly green-blind. Of the usually more prevalent type, (red-blindness,) but four cases were detected. The total amount of red-blindness was therefore less than 6 per cent. Among the female students, on the other hand, but two cases of green-blindness were found, and in both the deficiency was very slight; while four cases of incomplete red-blindness were recorded.

Even this great excess of green-blindness over the other common variety is not unprecedented. Dr. Krohn, who tested 1,200 railroad employes in Finland, found the ratio of green-blindness to red-blindness to be even larger—*i. e.*, 25: 4. More commonly, however, the latter is the prevailing type; to the extent in Favre's tests upon French railways, for instance, of 13: 1.

The great differences exhibited in color-blind tests, in different parts of the world, are doubtless to a considerable extent due to the different methods pursued, and in the earlier investigations, to the very imperfect knowledge of the subject possessed by those

*For an account of the principal European investigations prior to 1877, see F. Holmgren; *De la Cécité des Couleurs dans ses rapports avec les Chemins-de-fer et la Marine*, Stockholm, 1877. (Translated in Smithsonian Reports for 1877.)

†See B. Joy Jefferies' work (Color-blindness and its Detection, Boston).